Study on Fabrication of Superconducting RF 9-cell Cavity for ILC at KEK

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Abstract

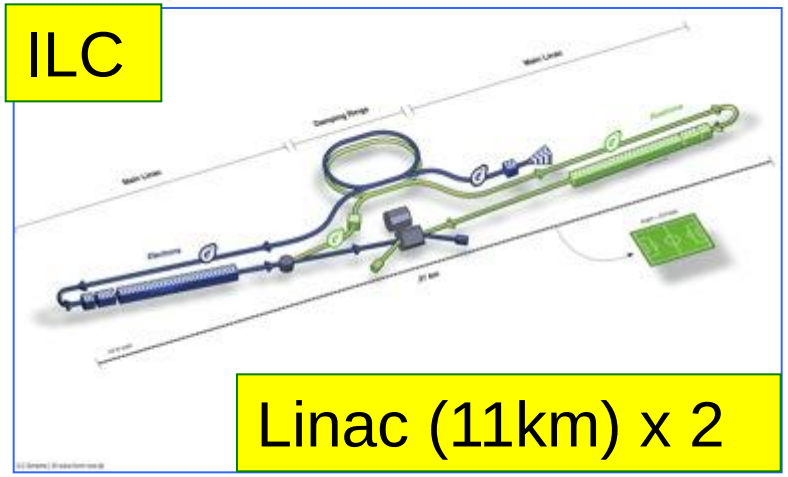
We constructed a new facility for the fabrication of superconducting RF cavity at KEK from 2009 to 2011. In the facility, we have installed a deep-drawing machine, a half-cell trimming machine, an electron-beam welding machine, and a chemical etching room in one place. We started the study on the fabrication of 9-cell cavity for International Linear Collier (ILC) from 2009 using this facility. The study is focusing on the cost reduction with keeping high performance of cavity, and the goal is the establishment of mass-production procedure for ILC. This article reports the current status of the studies in CFF.

Contents

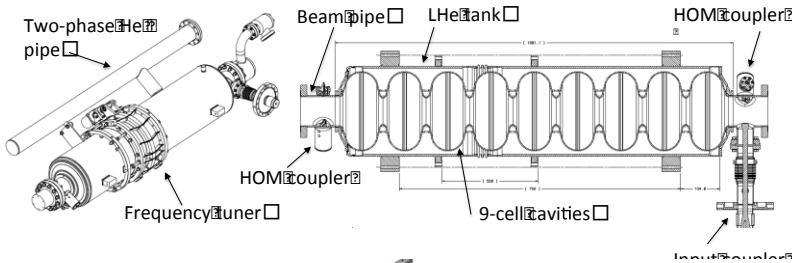
SCRF Industrialization required for ILC

Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.5 x10^{34} $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
Av. field gradient	31.5 MV/m +/-20% Q_0 = 1E10
# 9-cell cavity	16,024 (x 1.1)
# cryomodule	1,855
# Klystron	~400

ILC



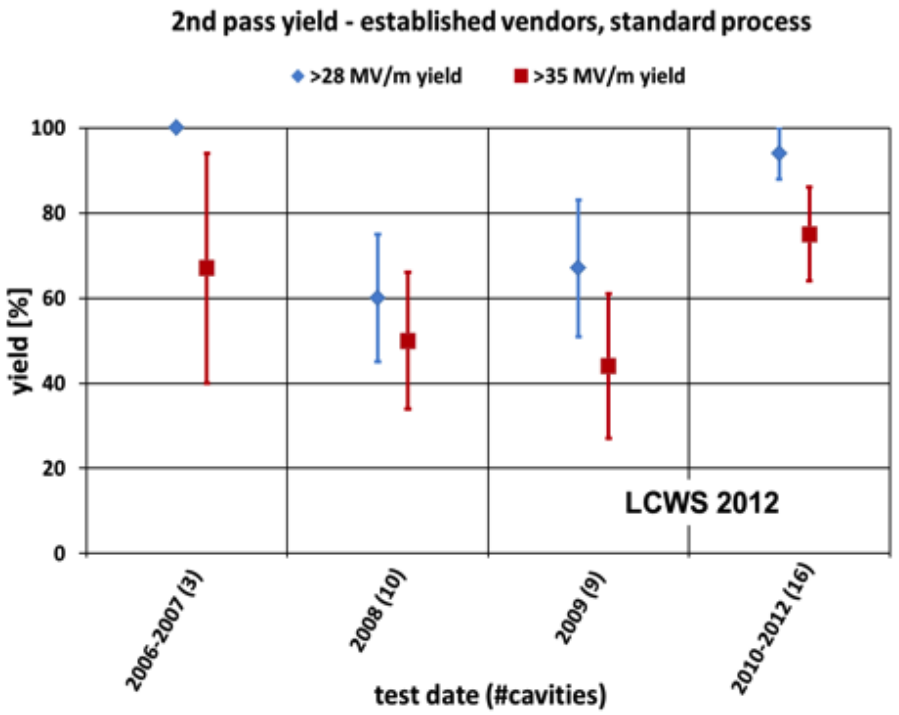
Linac (11km) x 2



High quality

16024 x 1.1(Yield = 90%)
~ 17600 cavities of mass-production

Progress in SCRF Cavity Gradient

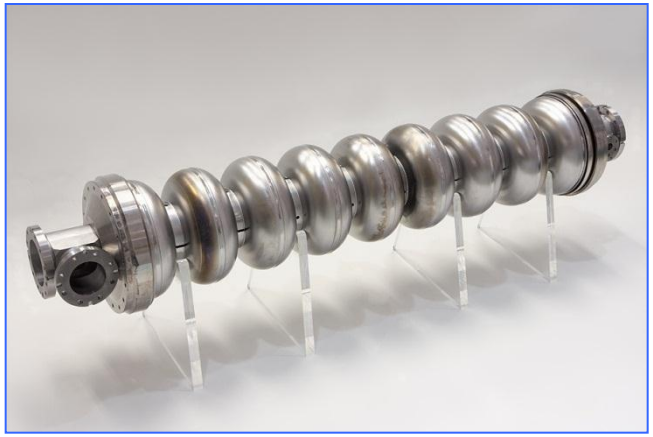


Production yield:
94 % at > 28 MV/m,

Average gradient:
37.1 MV/m

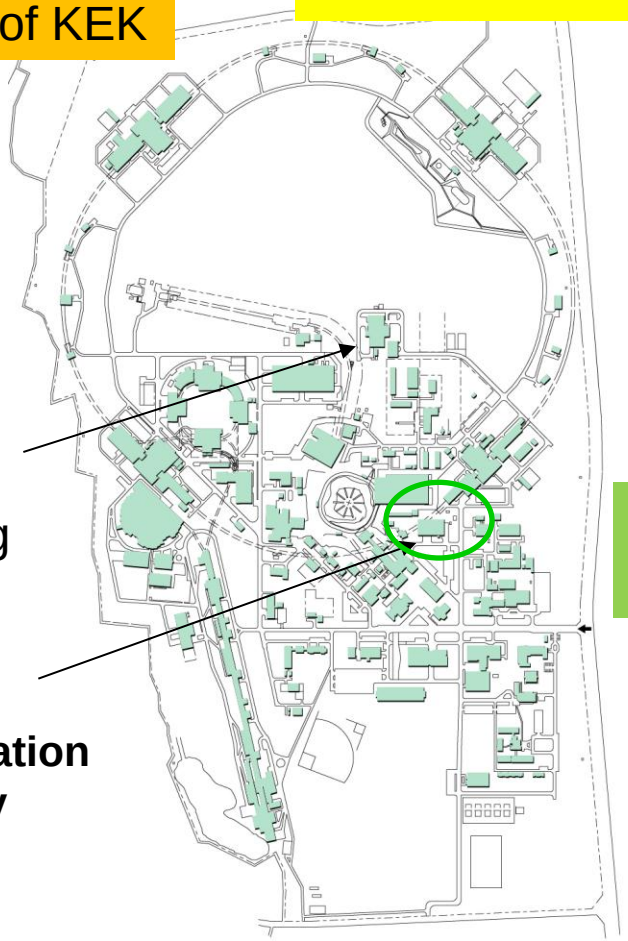
reached (2012)

Issues of mass-production:
High Quality Assurance (QA)
Cost Reduction



Construction of Cavity Fabrication Facility (CFF)

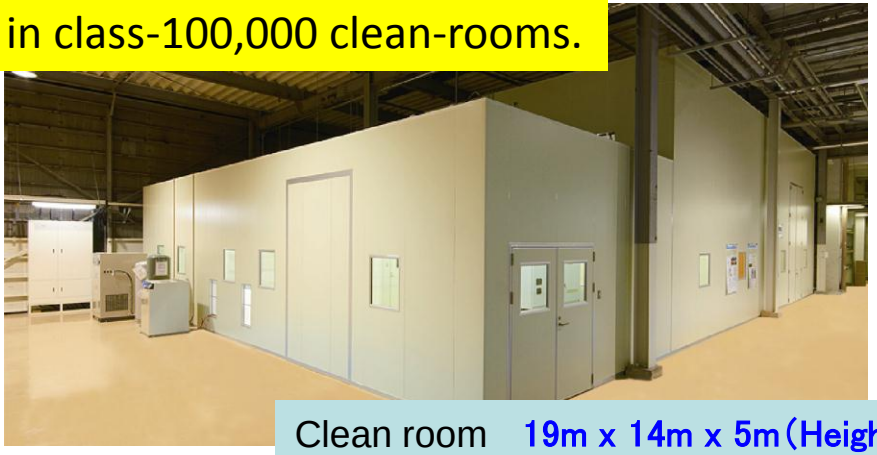
Map of KEK



STF building

Cavity Fabrication Facility (CFF)

All machines are in class-100,000 clean-rooms.



Clean room 19m x 14m x 5m(Height)

Class-100,000 / ISO 8 (Specification)

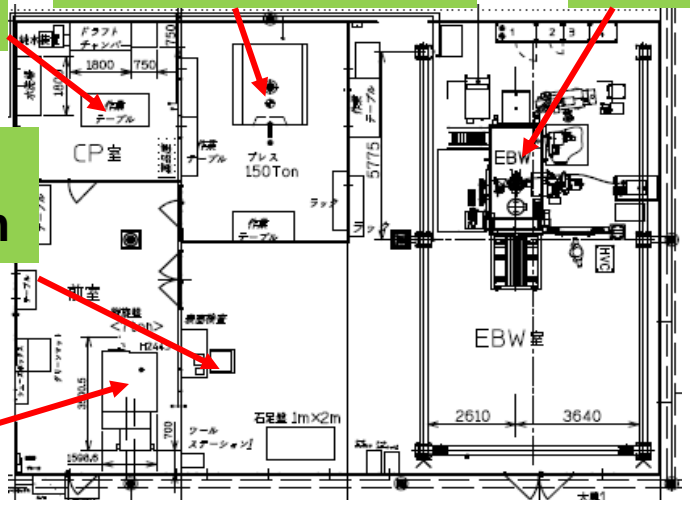
Chemical treatment

Press machine

EBW

Surface inspection

Vertical lathe



Clean room floor layout of CFF

Construction finished in FY2011

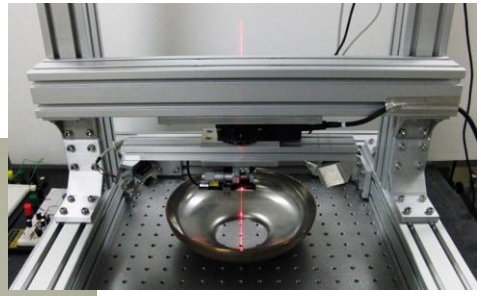
Main Equipments of Cavity Fabrication Facility

EBW room

Installation of EBW machine started from April 2011 and finished in July 2011.

Chemical Piloshing room

Located in on place: Very important for QA.



Measuring system for half-cell shape (Under developing)

Inspection equipment for Nb surface

Press machine (servo control)

Vertical lathe for half-cell trimming

Purpose of Cavity Fabrication Facility (CFF)

- High performance / high yield rate = Good QA
- Reduction of fabrication cost
- R&D of mass-production processes/fixtures

All necessary machines for cavity-fabrication are in one place: Efficient R&D

Cooperation with STF (Surface treatments / VT in Lab.)

Studies in CFF

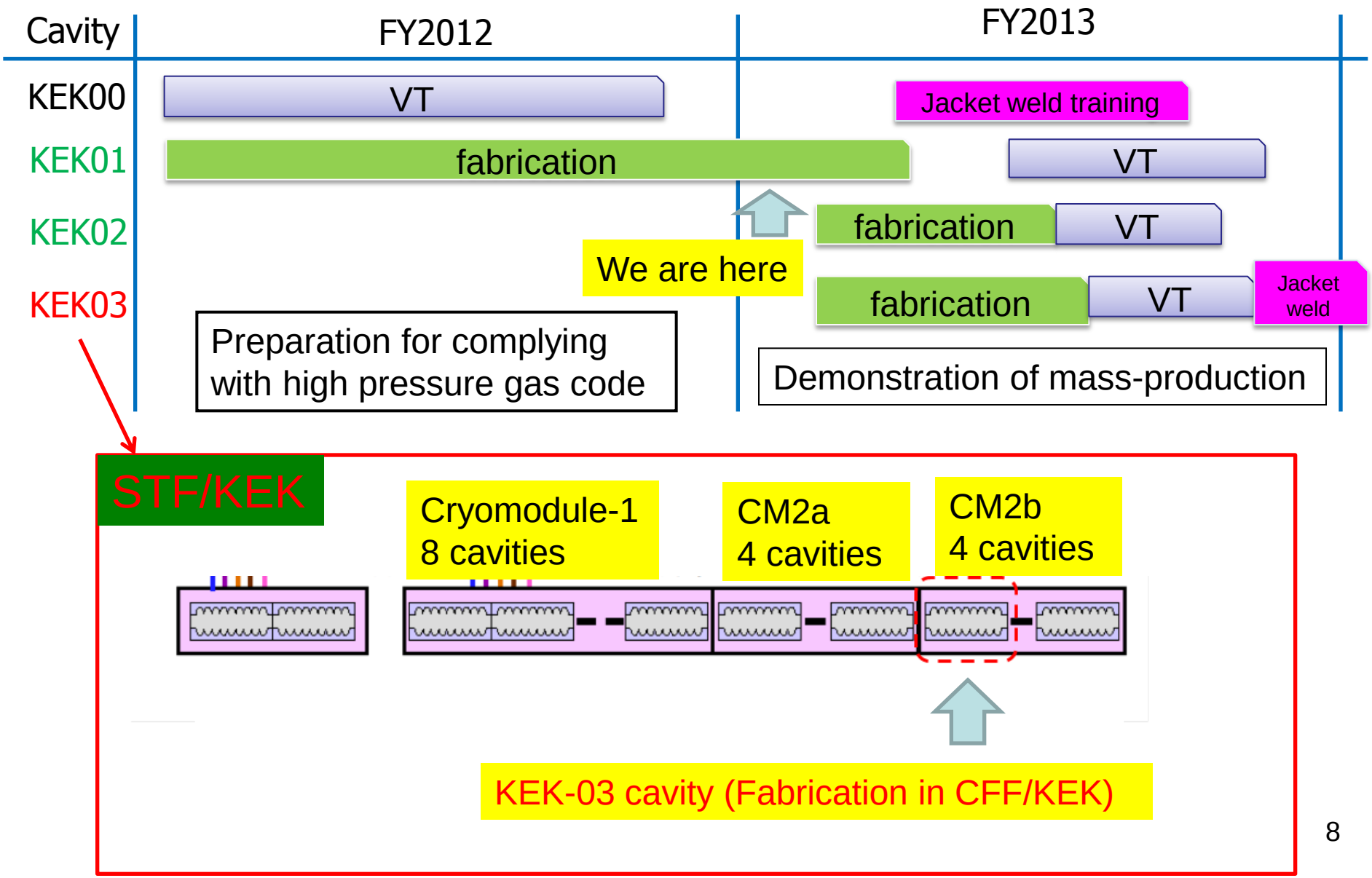
Cooperation with vendors (industries)

Speed up the R&D to establish the standard recipe for mass-production

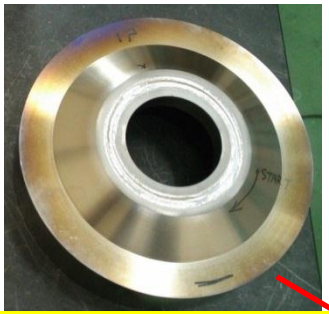
Open to other lab. / venders

Target is realization of mass-production technology for 17,000 cavities (ILC).

Plan/Purpose of cavities in CFF/KEK



Fabrication of KEK-00 Cavity (w/o HOM)



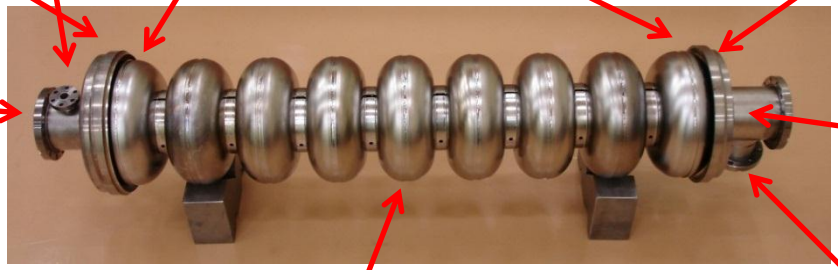
End-Plate (Ti) + Nb ring

Beam-pipe (Nb)

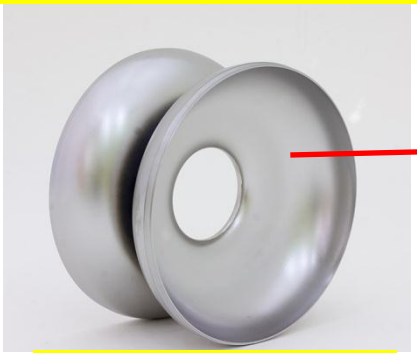
End-cells (Nb)

End-Plate (Ti) + Nb ring

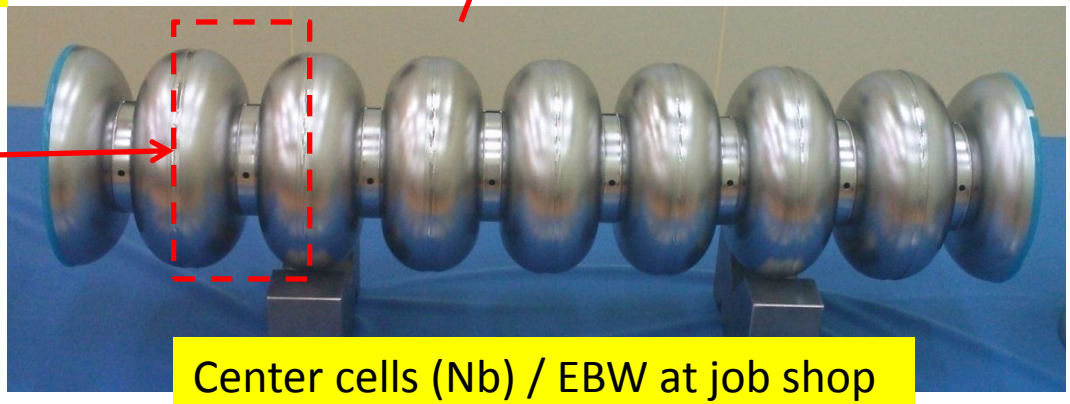
Flanges (Nb-Ti alloy)



Beam-pipe (Nb)



Dumb-bell (Nb)



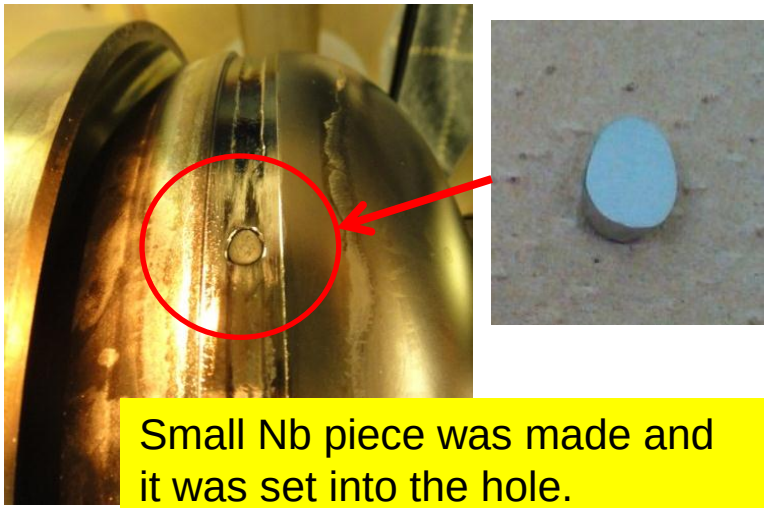
Center cells (Nb) / EBW at job shop

Input-port pipe (Nb)

Repair of 9-cell cavity KEK-00 in CFF/KEK

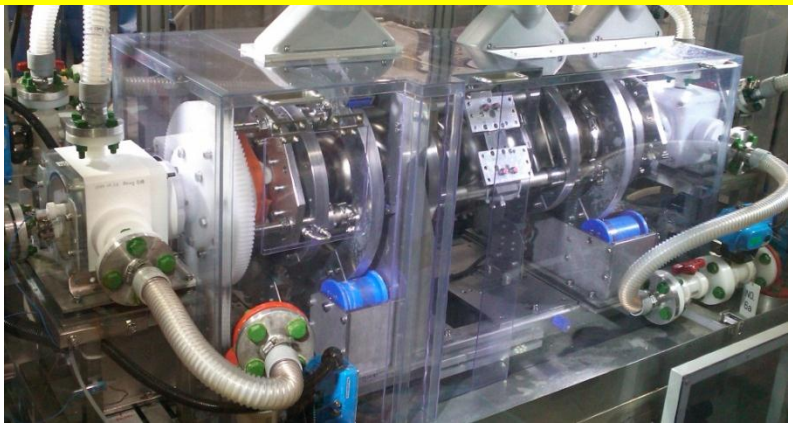
Failure in EBW of Cell#1 in job-shop

Contamination in welding joint?



Small Nb piece was made and it was set into the hole.

Bulk EP (100 um), Degreasing (50 ^{0}C, 30 min.), HPR (1.5 h), Annealing(4 h, 750 ^{0}C), and final EP (20 um) were performed in STF/KEK.



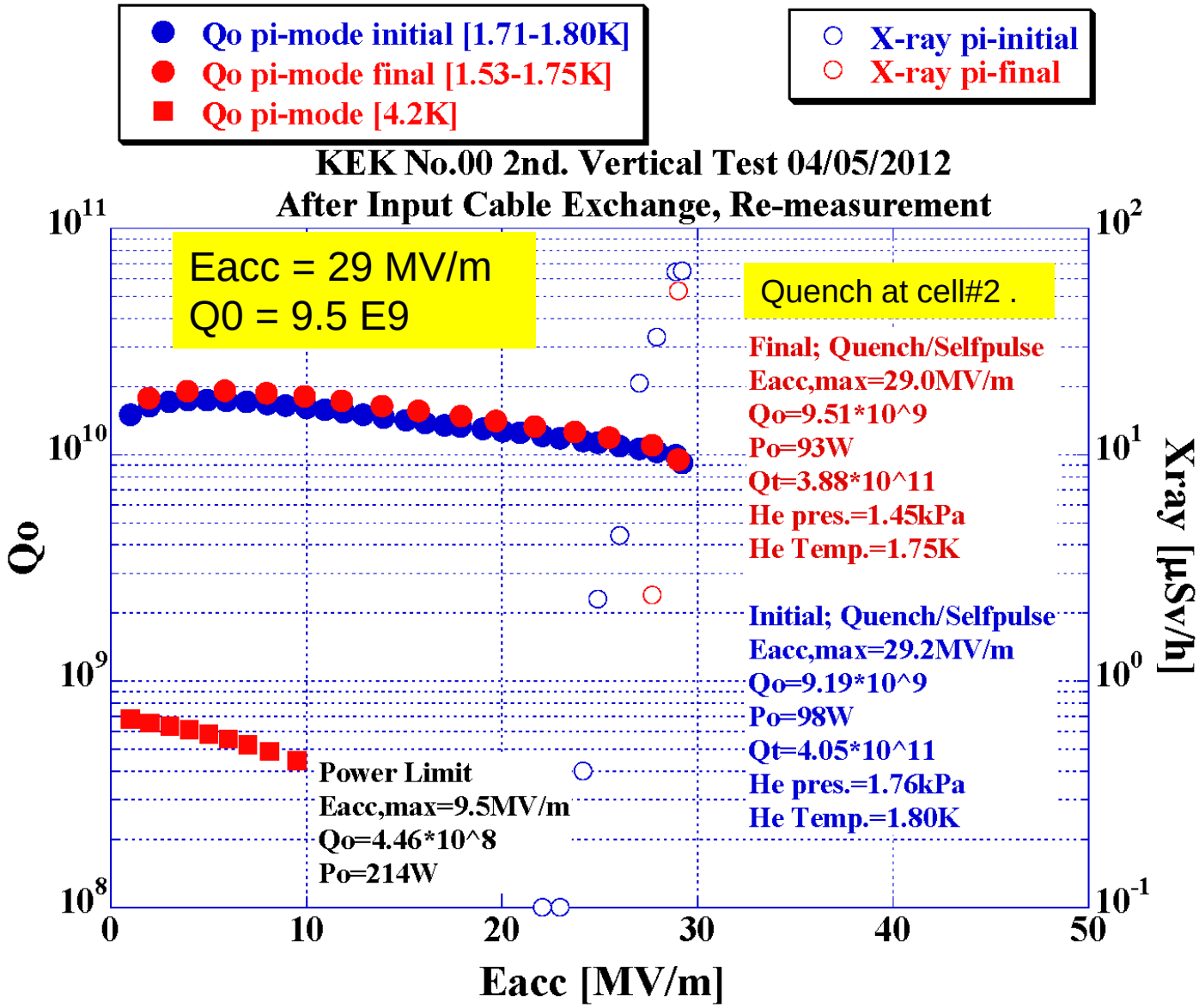
EBW bead

EBW bead

Re-EBW

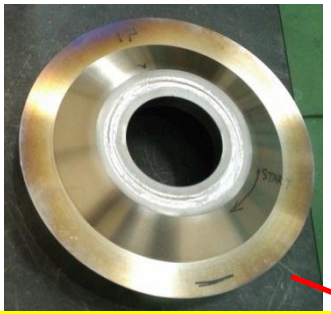
EBW with 120kV, 20mA, and 5 mm/s.

Vertical Test of 9-cell cavity w/o HOM (KEK-00) at STF/KEK



Cell#1 (repaired cell) reached to 42.7 MV/m in the 6pi/9 mode.

Fabrication of KEK-01 Cavity with HOM

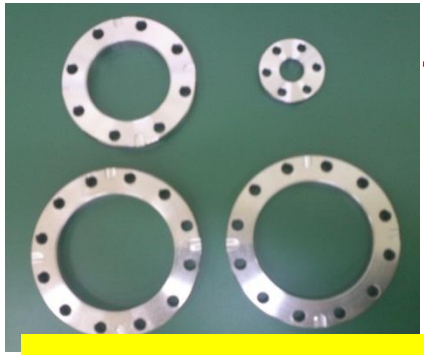


End-Plate (Ti) + Nb ring

HOM coupler (Nb)

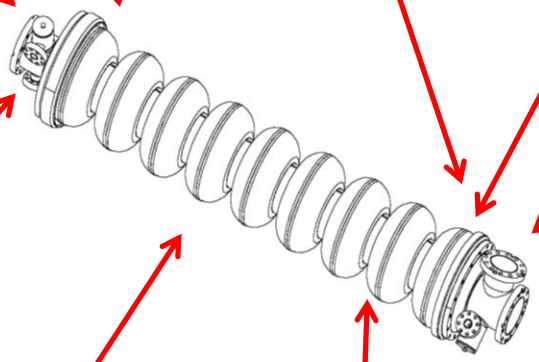
End-cells (Nb)

End-Plate (Ti) + Nb ring



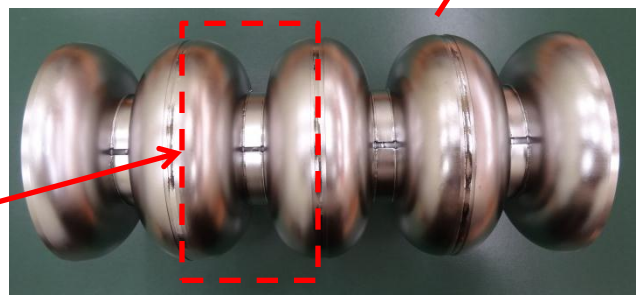
Flanges (Nb-Ti alloy)

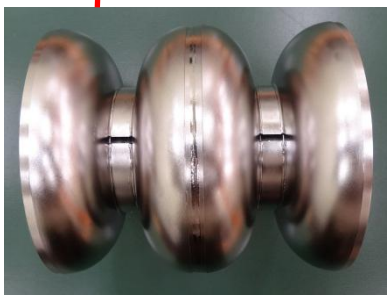
Beam-pipe (Nb)



Beam-pipe (Nb)

Dumb-bells (Nb)





Center cells (Nb) / EBW with horizontal beam in CFF

Input-port pipe (Nb)

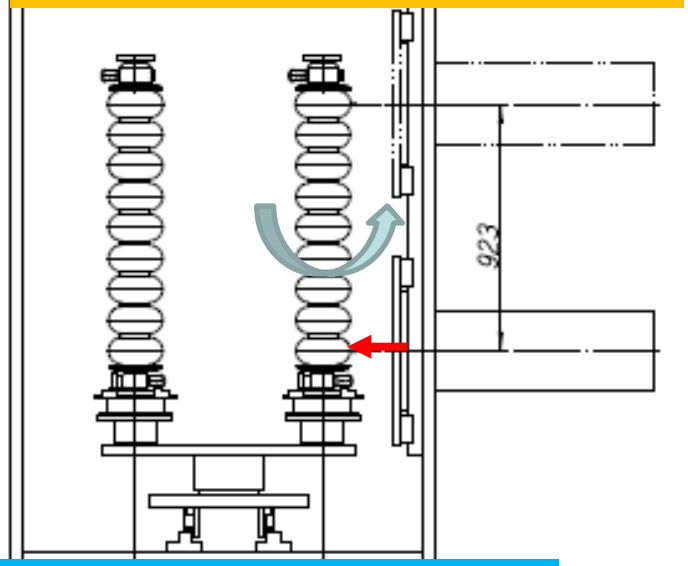
Configuration choice of cavity attitude and gun position

Direction of electron beam is vertical.

Setting cavity in horizontal way is rather compllicated (KEK-00).

Direction of gravity.

Direction of electron beam is horizontal.

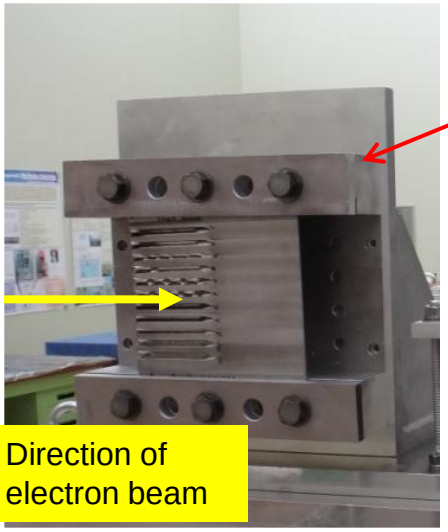


Setting cavity in vertical way is simple (KEK-01).

Stacking dumbbells is easy in the vertical configuration of cavity.

Better for mass-production.

Set-up of Nb-plate test for side-gun configuration

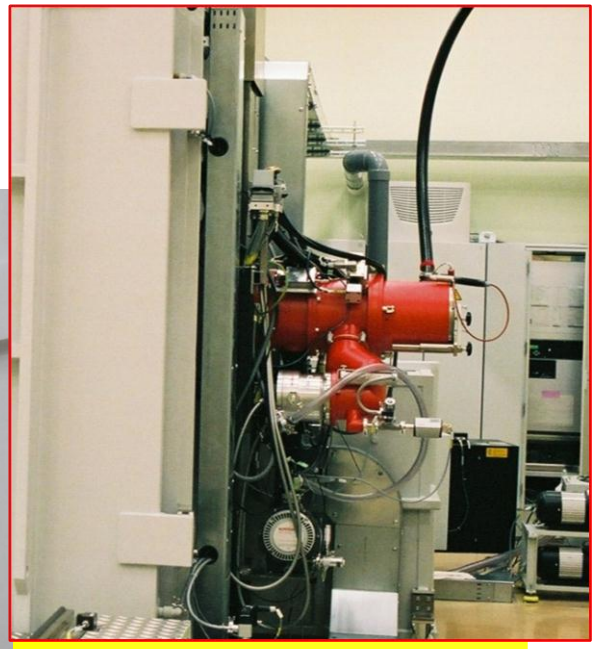


Direction of electron beam

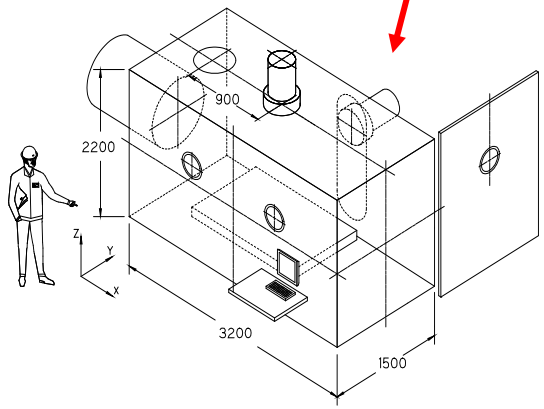
Fixture for Nb plates

Direction of electron beam

Alignment target

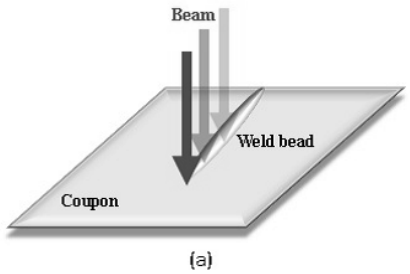


Gun on the side-wall

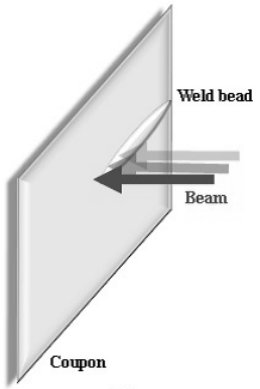


Studies on EBW parameter

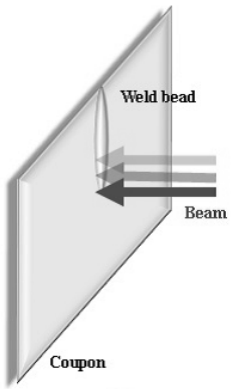
Search for good EBW parameter was done by changing the welding beam-voltage, beam-current, focus-current, working-piece distance from gun, working-piece moving speed, Nb-plate thickness, and the gun and working-piece configuration.



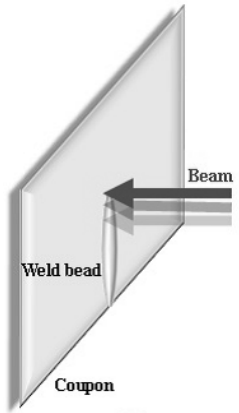
Vertical beam



Horizontal beam
(See next slide)



Horizontal beam
Downward welding

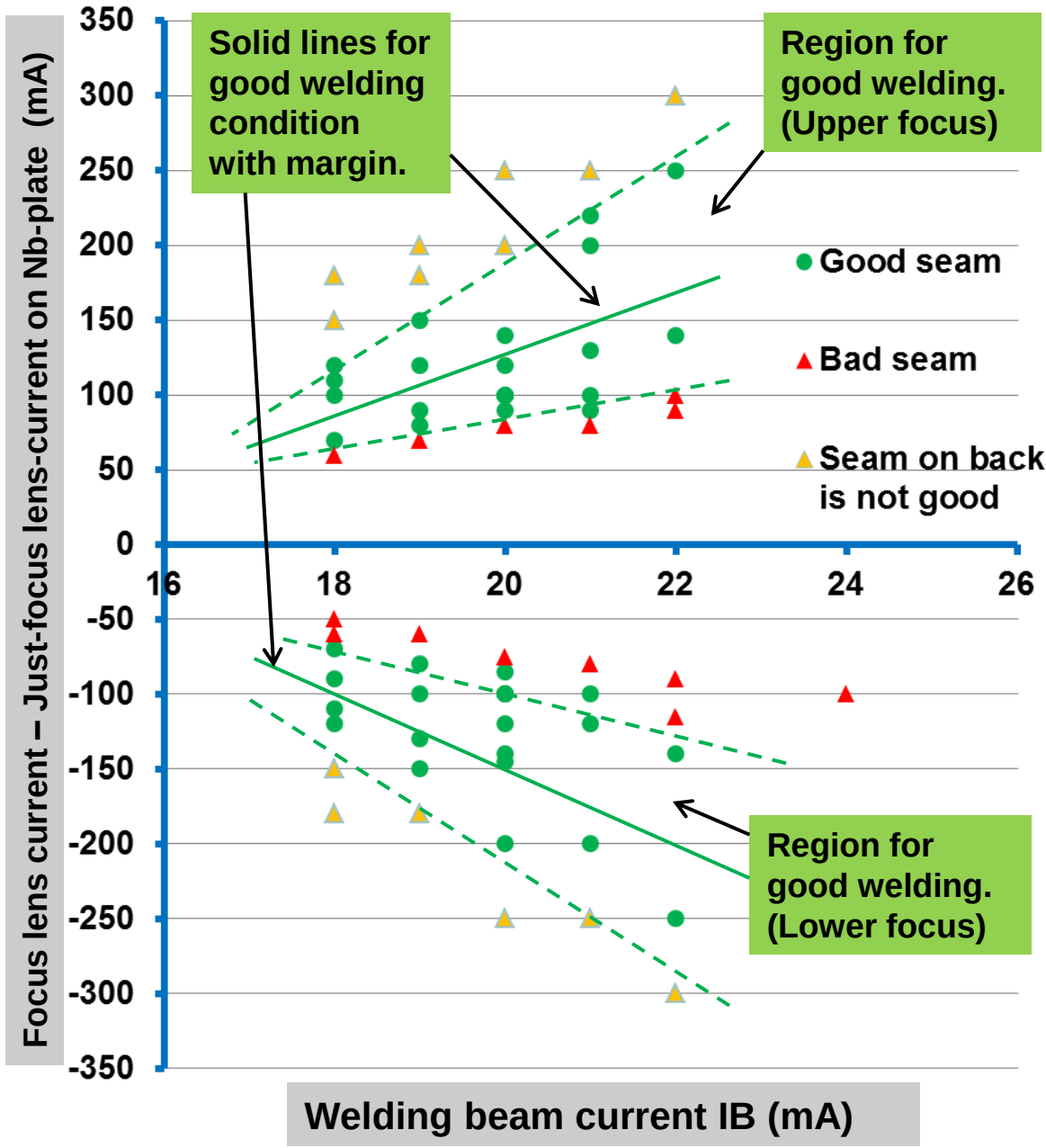


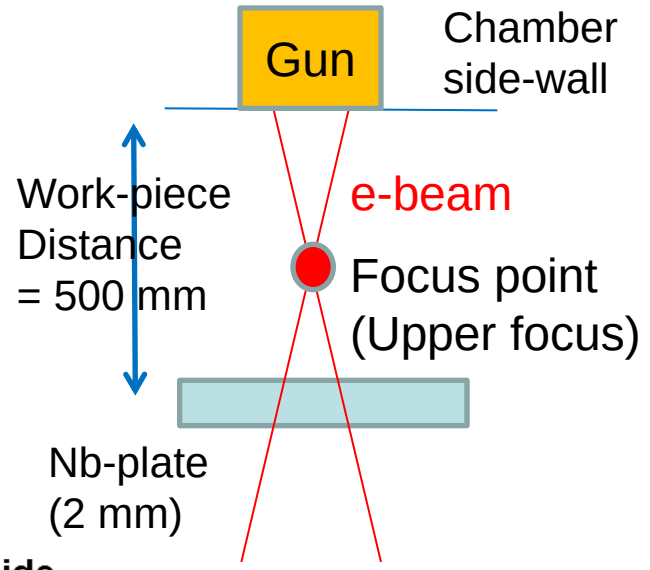
Horizontal beam
Upward welding

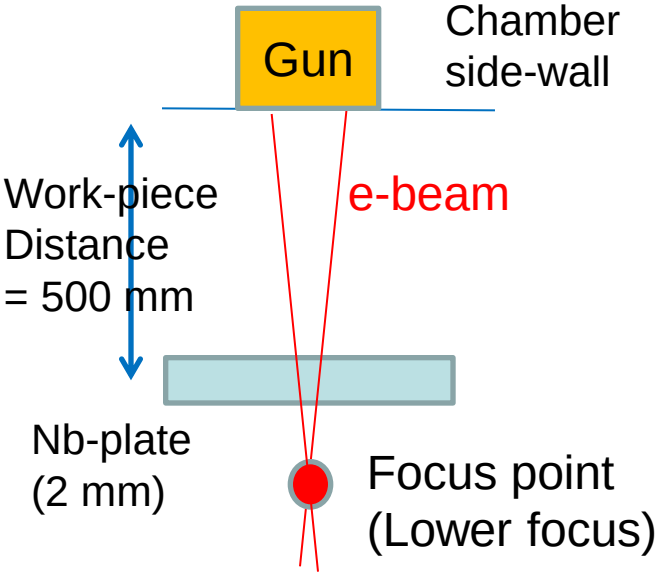
In particular, the gun and working-piece configuration affects the results of welding seam.

For more details of studies on EBW parameters , see following presentation.
ID: 3364 - WEPWO015 / 15th May (Wed.), poster session by T. Kubo (KEK):
Title: Electron Beam Welding Parameters for High Gradient Superconducting Cavity

Voltage = 120 kV, Moving speed = 5 mm/sec., Work-piece distance (W.D.) = 500 mm, Nb-plate thickness = 2.0 mm

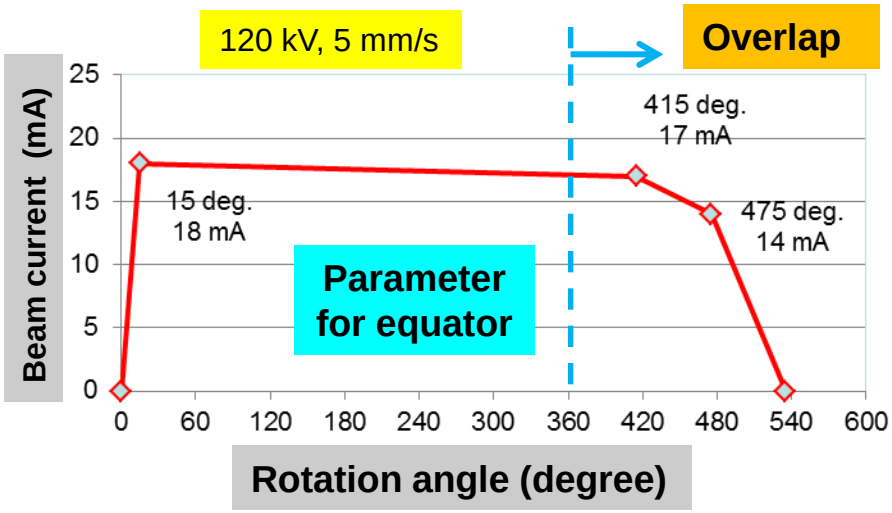


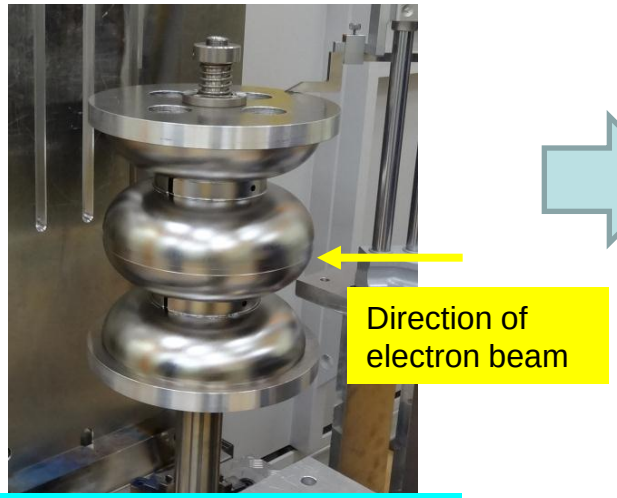




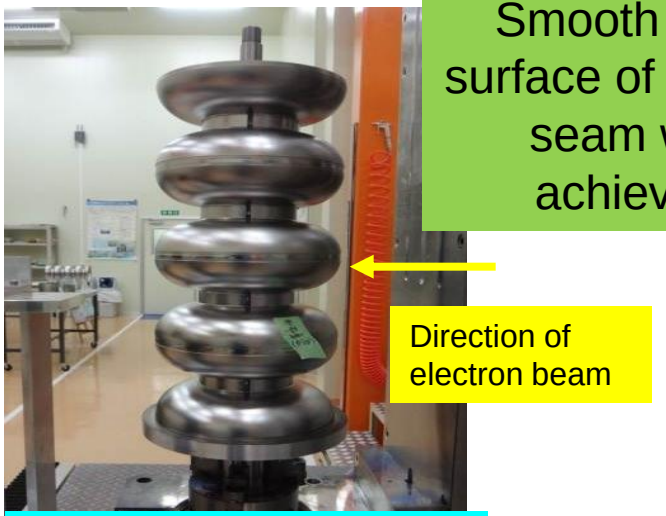
EBW at equator for stacked dumbbells (KEK-01)

EBW test by a dummy Nb-pipe



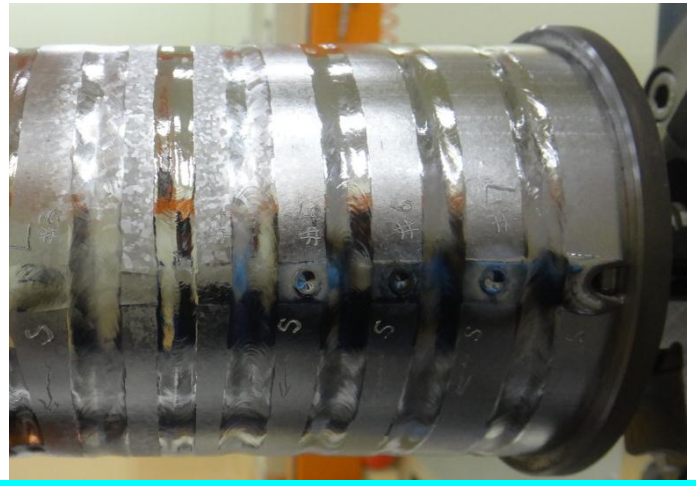


EBW of 2-dumbbell



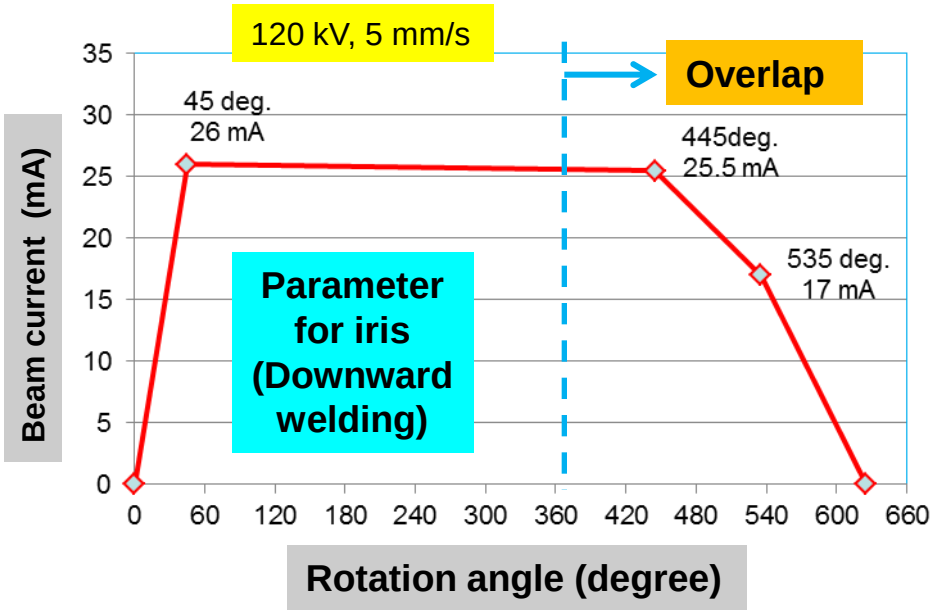
EBW of 4-dumbbell

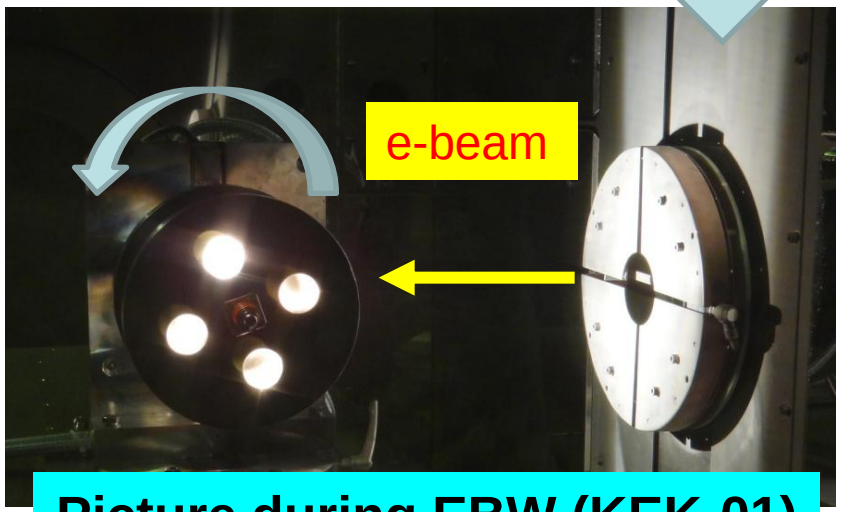
EBW of dumbbell at iris (KEK-01)



EBW test by a dummy Nb-pipe

Setup of dumbbell EBW for side-gun

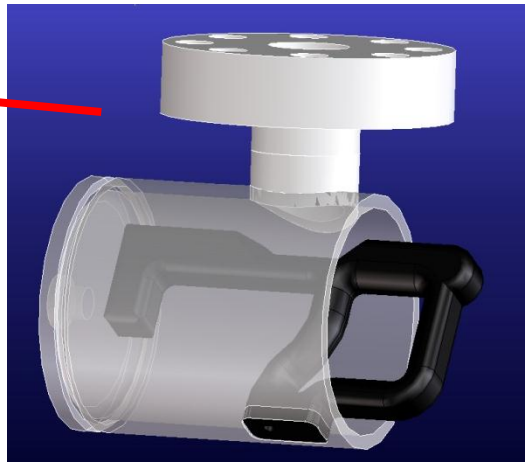




Picture during EBW (KEK-01)

Fabrication of HOM cup by deep-drawing for KEK-01

End-group shape is complicated and then there is a possibility of cost-reduction in fabrication.

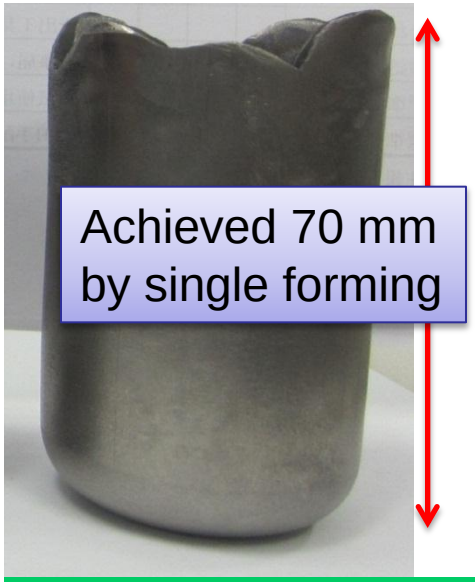


HOM cup（φ48×64）

Conventional method：Deep-drawing by multiple press-forming with annealing.

New method：Deep-drawing by single press-forming.

Nb sheet thickness: 2.8 mm



Trial to fabricate the freq. tuning tab by press-forming. (Under study)

Collaboration with industry:
Shinohara Press Service Co. Ltd.

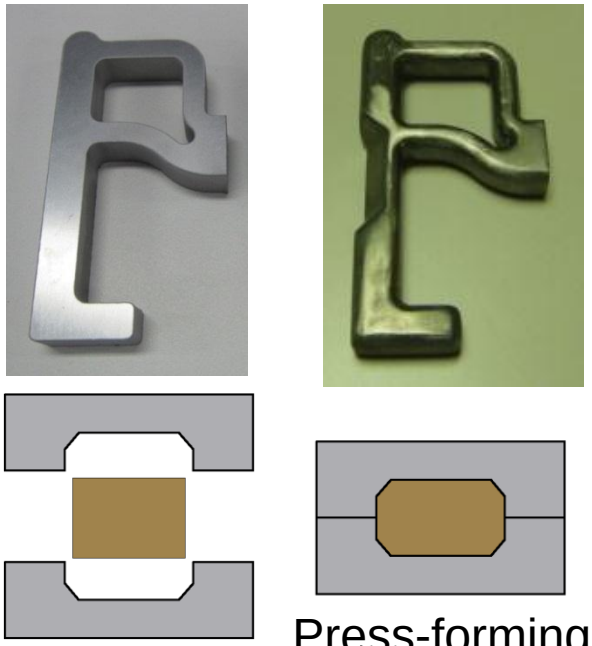
SHINOHARA

Fabrication of HOM antenna by water-jet cutting and press-forming for KEK-01

Conventional method: Machining
New method: Water-jet cutting
+ Press-forming

Water-jet cutting in a job shop

Collaboration with SHINOHARA



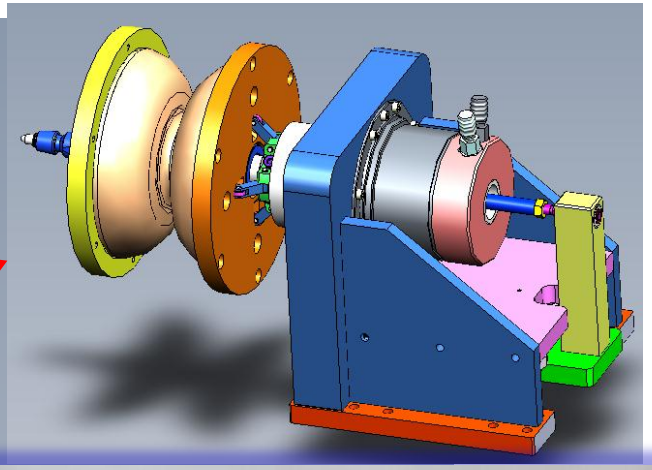
Press-forming

Result of low power test is OK. (Master thesis by F. Yasuda, Jan. 2013, the university of Tokyo, JAPAN)

Design of loader for multiple dumb-bells

Pumping time (~30 min.) and cooling time (~30 min.) are duplicated in EBW processes.

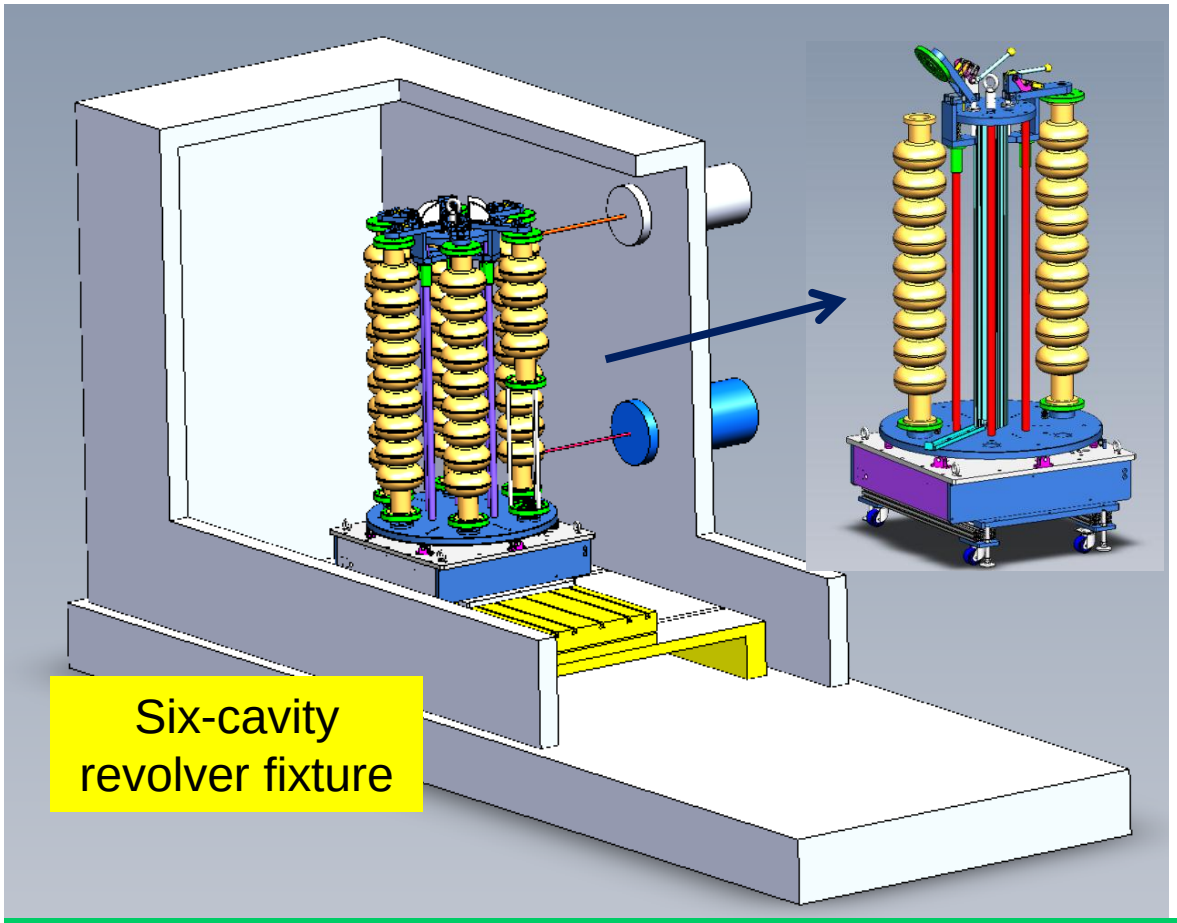
e- gun on side



Proto-type of four-dumbbell loader

Multiple dumbbells are loaded inside the EBW chamber at once and the EBW of dumbbells will be done continuously after pumping down.

Design of 9-cell cavity fixture for EBW machine



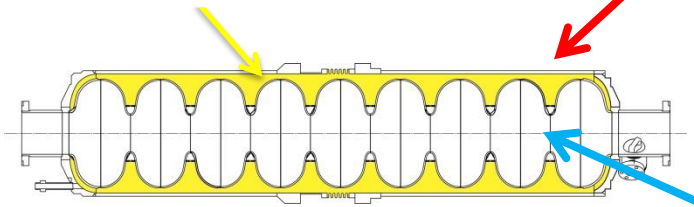
Six-cavity revolver fixture

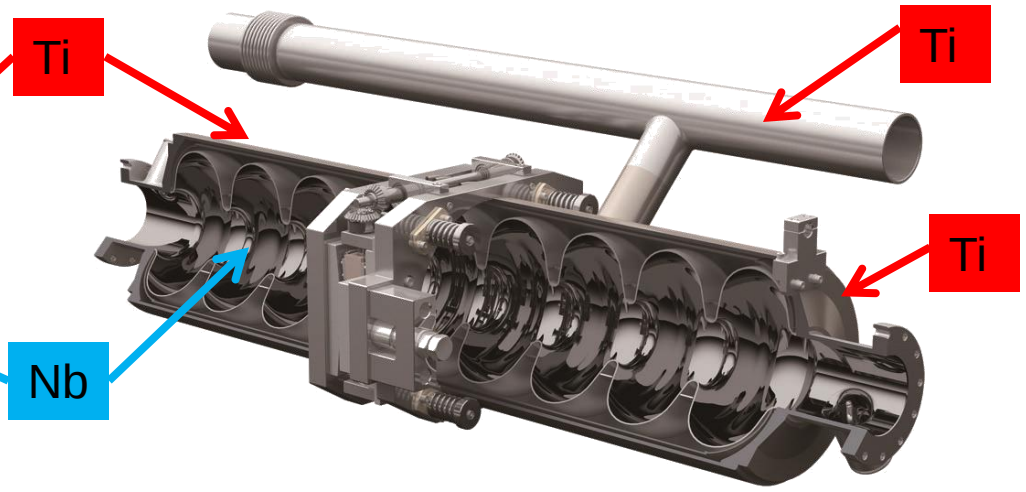
Proto-type of revolver fixture

Pumping time (~30 min.) and cooling time (~30 min.) are duplicated in EBW process. The time is reduced if multiple-seams are welded in one pumping cycle.

Japanese High-Pressure Gas safety act

He in-between the Ti-jacket and Nb cavity





One must fabricate cavities complying with Japanese High-Pressure Gas (J-HPG) safety act if we use the cavities in accelerators.

For cavities by venders,
Manufacturer: KEK
Applicant: venders

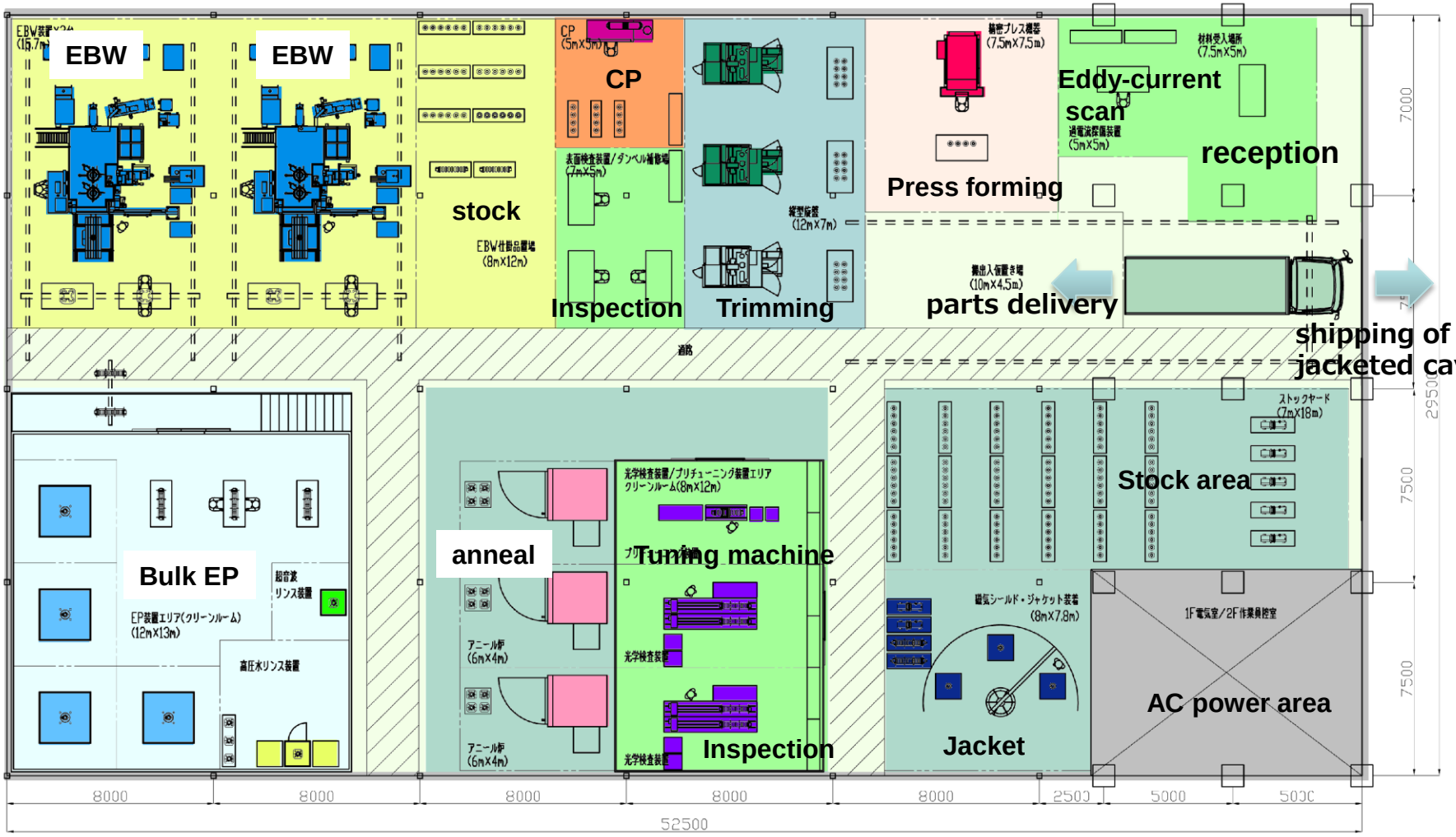
For cavity KEK-03 in CFF,
Manufacturer: KEK
Applicant: KEK/CFF

In case of ILC in Japan, a significant fraction of cavities might be imported from foreign vendors. KEK/CFF can guide them for the procedures of J-HPG safety act.

Estimation of cavity production plant

KEK-MHI

Simulation study assuming CFF housing area（53m x 30m）



Assuming Nb plates for cell, fabricated end-group parts are input, 200 working days/year, 2 shifts/day with 30 people times 2 shifts

Max. production rate will be ~530 cavities/year, ~2650 cavities for 5years.

Assuming that final treatment and vertical test will be done in other place.

Summary

- In order to realize the mass-production technology of ILC for ~17,600 cavities, we constructed Cavity Fabrication Facility (CFF) at KEK and the installation of all equipment finished in July 2011.
- The maximum acceleration gradient of cavity KEK-00 w/o HOM which was fabricated in job-shop + CFF reached 29 MV/m.
- Fabrication of KEK-01 with HOM is ongoing in CFF.
- We are planning to fabricate 2 more cavities (KEK-02, 03) in CFF. Cavity KEK-03 will be fabricated complying with Japanese High Pressure Gas (HPG) safety act and will be installed in CM in STF/KEK.
- Mass-production studies are ongoing in parallel. Fabrication methods of HOM-cup and HOM-antenna are improved for KEK-01. 6-cavity fixture and multi-dumbbell loader for EBW machine are designed and some proto-types are made.
- Plant simulation study on mass-production of cavities is done in collaboration with industry.